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Humus profile degradation as influenced by decreasing earthworm activity

S. P. J. van Delft[1], J. C. Y. Marinissen[2] and W. A.M. Didden[2]

[1] The Winand Staring Centre for Integrated Land, Soil and Water Research, PO Box 125, 6700 AA Wageningen, The Netherlands
[2] Wageningen Agricultural University, Department of Environmental Sciences, Wageningen, The Netherlands

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Summary. Three humus profiles were sampled in moist grasslands on loamy sand, representing a chronosequence of an acidifying ecosystem. Over the chronosequence, earthworm activity decreased, from high activity to complete absence of earthworms. We studied the organic matter at three observation levels: the humus-profile, the aggregate and the soil organic matter (SOM)-fraction level. With decreasing earthworm activity a trend in separation of organic and mineral elements can be discerned. Humus forms changed from Vermimull via Vermic Rhizomull to Rhizic Mullmoder. With decreasing earthworm activity, particulate organic matter (POM) first changes from intra- to extra-aggregate POM, and accumulates completely on top of the mineral soil in the absence of earthworms. The trend in vegetation that follows this changes in organic matter morphology indicates that less nutrients become available with increasing acidification . The decrease in earthworm activity thus seems to be related with an overall decrease of SOM and nutrient dynamics.

Key words: Earthworm activity, SOM fractions, soil aggregates, POM (particulate organic matter) decomposition

Introduction

Earthworms contribute significantly to organic matter turnover, ingesting large quantities of fresh litter (Satchell 1963). The litter is fragmented and incorporated in soil aggregates. Stockdill (1966) has described aggrading profiles for New Zealand conditions and by Hoogerkamp et al. (1983) for Dutch polders. In both studies, profiles were originally devoid of earthworm activity, which had resulted in an organic matter cycle external from the mineral soil. We studied a chronosequence of degrading profiles, starting with a completely homogenised profile, in which earthworm activity becomes increasingly hampered. We expected to find a decrease in fragmentation of organic material with decreasing earthworm activity, and a development towards accumulation of organic matter outside the mineral part of the soil. We studied the profiles both macromorphologically and micromorphologically. Furthermore, we studied the distribution of carbon in different fractions both at the soil aggregate and the intra-aggregate level.

Corresponding author: S. P. J. van Delft

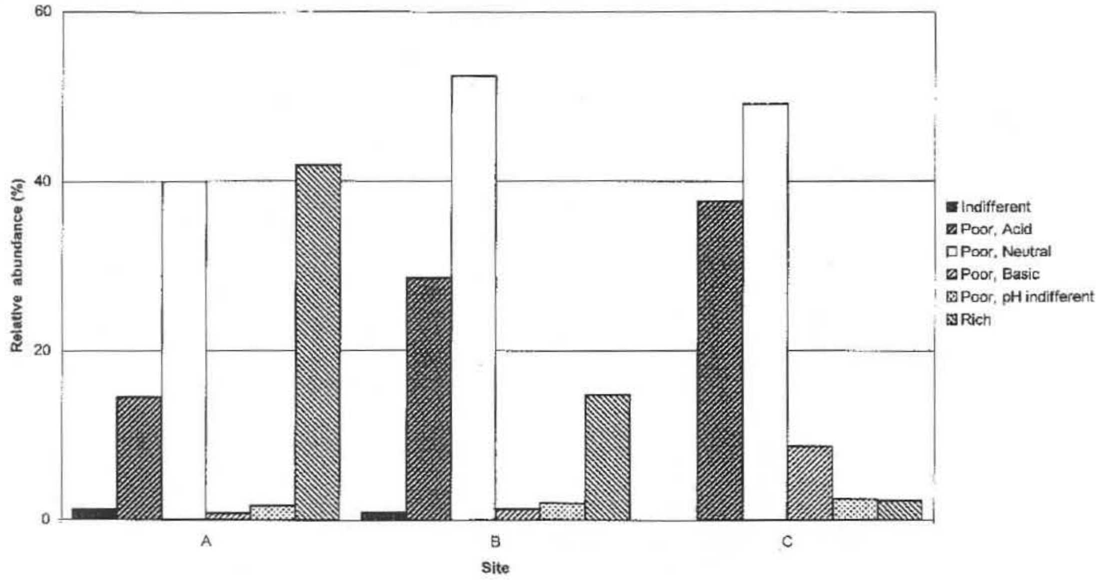

Fig. 1. Ecological spectra for the vegetation of the study sites for trophic level and acidity (after Runhaar et al. 1987)

Materials and Methods

Three humus profiles were sampled in moist grasslands on loamy sand, representing a chronosequence of an acidifying ecosystem. The study site was a nature reserve called 'Groot-Zandbrink', located in a brook valley in the central cover sand area of The Netherlands. Three profiles were selected, ranging from the original soil profile (A) to a profile devoid of earthworms (C). In this low-lying area rainwater infiltrating from the adjoining higher regions comes to the surface as seepage water. While percolating through the subsoil, the water is enriched in basic cations, mainly Ca^{2+}. Thus so-called 'beekeerdgronden' (De Bakker & Schelling 1989) are formed, characterised by an Ah-horizon of at least 15 cm and gley properties starting within 35 cm of the surface. In these soils pH is buffered between 5 and 6.5 by a high cation-saturation due to the Ca^{2+} – rich seepage water. Because of improved drainage to satisfy agricultural needs, groundwater levels at profiles B and C have dropped dramatically. This has affected buffering capacity due to replacement of seepage water with infiltrating rainwater, leading to a reduced pH after depletion of basic cations. Species composition of the vegetation indicates a shift from moderately nutrient rich conditions at location A to nutrient poor and acid conditions at location C (Fig. 1).

Sampling

The humus profile of each location was described using the classification system of Klinka et al. (1981), improved by Green et al. (1993) and modified by Van Delft (1995a, 1995b)[1] for use in grassland ecosystems. From each profile, only the organic mineral layers were sampled for micromorphological and aggregate-analysis. Micromorphological sections (7 × 7 cm) were prepared, and studied for frequency and distribution of mineral particles, macropores, organic matter and signs of biological activity according to Bullock et al. (1985).

[1] M- and Ahz-horizons were introduced by van Delft (1995a, 1995b) to describe the accumulation of root residues. Ahz-horizons are endorganic Ah-horizons with accumulated root residues and are considered as a transition to M-horizons . M-horizons are ectorganic horizons, consisting of a mat of root residues. Distinction is made according to decomposition grade: Mf (fibric); very few decomposition, most tissue well recognisable, Mm (mesic); partly decomposed OM and Mh (humic); most root residues are humified.

Material was dried and fractionated into aggregate size classes by dry sieving. Aggregates were sieved into large macro-aggregates (>2 mm), small macro-aggregates (0.5–2 mm), micro-aggregates (0.05–0.5 mm) and the fraction <0.05 mm. Free POM (particulate organic matter) was removed from fractions larger than 0.5 mm by aspiration. Five gram subsamples of the fractions >0.05 mm were dispersed by 16 hours end-over-end shaking with 5 glass beads (Ø 5 mm) in 30 ml demineralized water, and the amount of free sand determined by sieving with the appropriate sieve.

Carbon distribution within aggregates was studied by separating POM from the mineral material through a combination of wet sieving and decanting of the dispersed subsample. In POM a distinction was made between fine (<0.15 mm) and coarse (>0.15 mm).

Of each aggregate and intra-aggregate fraction C contents were determined by destruction using a modified wet combustion method (Dalal 1979).

Results

Soil profile level, macro- and micromorphology

In the three sites earthworm activity decreased and humus forms changed from Vermimull (profile A) via Vermic Rhizomull (profile B) to Rhizic Mullmoder (profile C) (Fig. 2)

The organic mineral horizon of profile A consisted of an Ah-horizon of 7 cm depth. On top of the profile, only 0.5 cm litter can be found. In the Ah-horizon, worm channels are abundant and commonly reworked. Active roots and root remains in several grades of decay can be found, partly eaten by soil mesofauna. A very large portion of the organic material is no longer morphologically recognisable but appears mainly in humic[2] form, confined within aggregates (Fig. 3A).

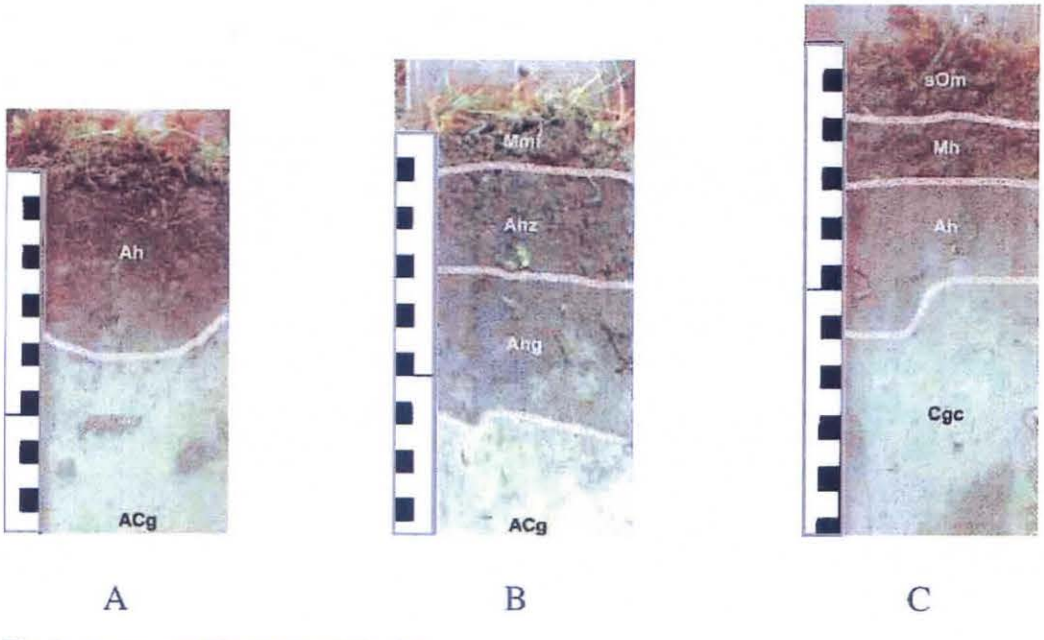

Fig. 2. Humus profiles of the study sites

[2] Term from Bullock et al. (1985) for micromorpholigcal description. It is not meant as humus senso stricto.

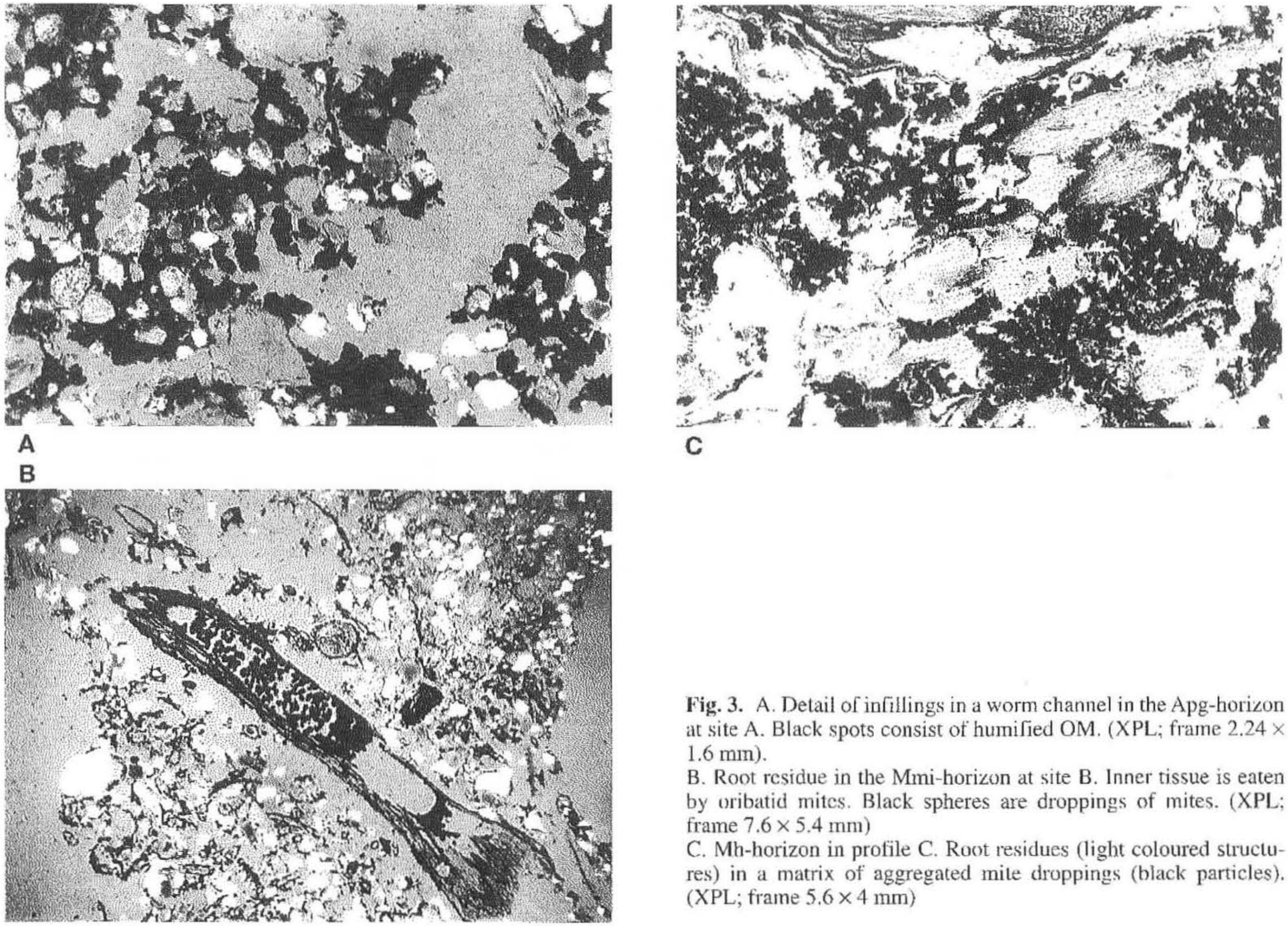

Fig. 3. A. Detail of infillings in a worm channel in the Apg-horizon at site A. Black spots consist of humified OM. (XPL; frame 2.24 × 1.6 mm).
B. Root residue in the Mmi-horizon at site B. Inner tissue is eaten by oribatid mites. Black spheres are droppings of mites. (XPL; frame 7.6 × 5.4 mm)
C. Mh-horizon in profile C. Root residues (light coloured structures) in a matrix of aggregated mite droppings (black particles). (XPL; frame 5.6 × 4 mm)

The organic profile B consists of a 2 cm thick Mm-horizon and two organic mineral horizons. The Mm-horizon is dominated by root residues (fine grass roots and medium woody roots of rushes) in several grades of decay. Some clusters of dropping of oribatid mites occur in or near root residues (Fig. 3B). A few earthworm casts are present, representing the only mineral contribution to this horizon.

The top organic mineral layer is a 4–6 cm thick Ahz-horizon, which consists mainly of dead roots in various decomposition stages. Worm channels are abundant, old channels are partly destroyed by new ones. Infillings of wormchannels consist of aggregates that contain much partly decomposed material.

The second layer is a 5 cm thick gleyic Ahg-horizon, in which aggregates contain more humic organic matter and less undecomposed root remains than those in the Ahz-horizon.

At site C clear ectorganic horizons overlay the mineral soil. The top horizon is a 3 cm thick sOm-horizon, consisting of partly decomposed *Sphagnum* residues, with a few clustered mite droppings. The Mh is a 3 cm thick horizon in which purely organic aggregated mite droppings are abundant (Fig. 3C). The Ah-horizon is 5 cm thick and consists of well sorted sand with fine organic matter, partly present as POM, but most as mite droppings or amorphous humic material. The POM present is largely decomposed. In the matrix some large aggregates can be recognized, which may be related to former earthworm activity. No active roots are present.

Aggregate level

The three soil profiles differ in the distribution of carbon over the aggregate fractions. As was also found in the micromorphological analysis, less free POM can be found in the Ah-horizon of profile A than in the Ahz- and Ah-horizons of profiles B and C (Fig. 4). In profile A most carbon is found within aggregates, both macro- and micro-aggregates.

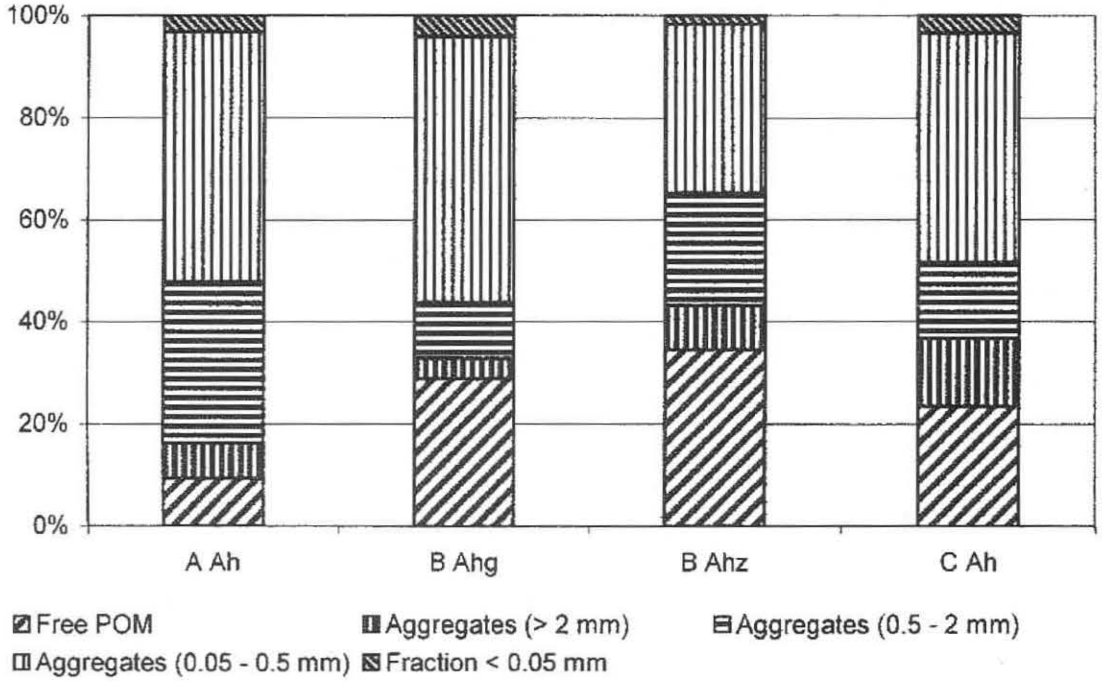

Fig. 4. Distribution of C over aggregate-fractions in the organic rich horizons of the 3 profiles

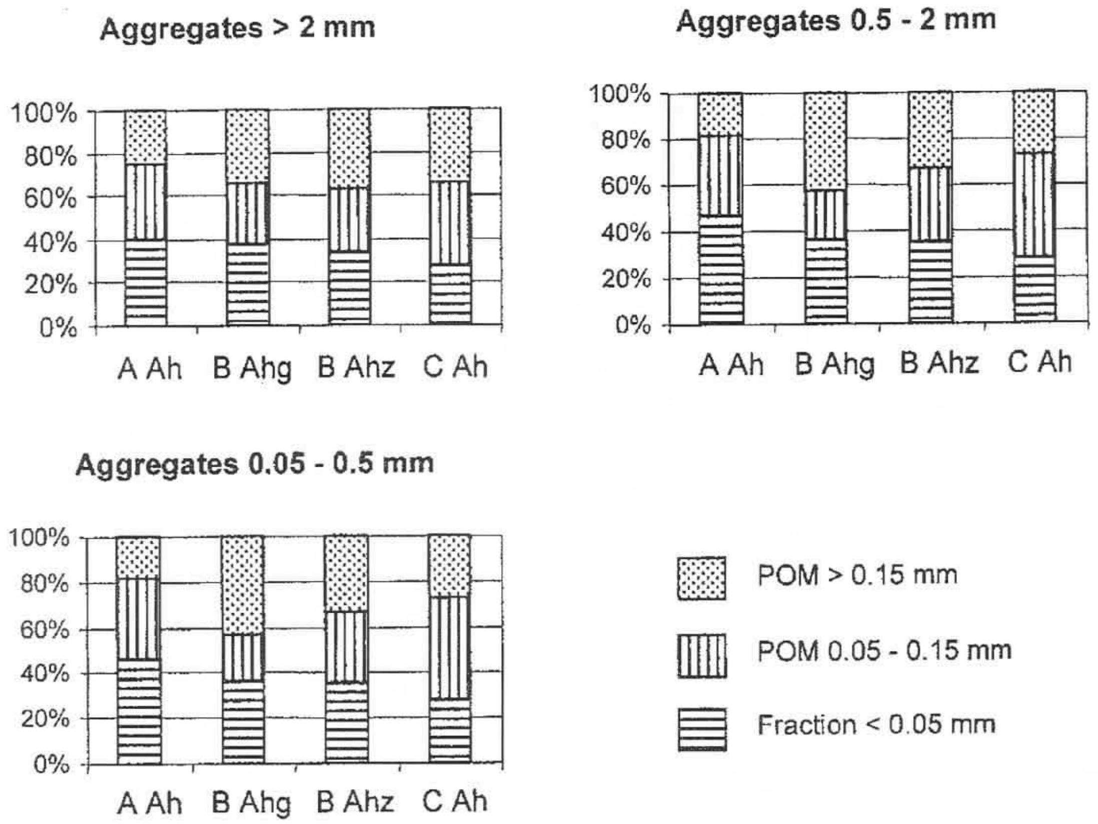

Fig. 5. Distribution of intra-aggregate C in aggregates from the organic rich horizons of the 3 profiles

Intra-aggregate level

In aggregates >2 mm POM, both coarse (>0.15 mm) and fine, increases with decreasing earthworm activity (Fig. 5). In the aggregate fractions 0.5–2 and 0.05–0.5 mm total POM also increases from profile A to C, but at the same time fine POM becomes relatively more important.

Discussion

With decreasing earthworm activity a trend in separation of organic and mineral elements can be discerned. This trend is visible on all levels of study, from field observation to sub-aggregate level. In profile A the only recognisable plant fragments are living or recently dead roots; the rest of the carbon is no longer recognisable (humus) in micromorphological samples. The external litter layer is almost absent. In profile B the external litter layer is slightly thicker than in profile A. In the mineral layer of profile B also more undecomposed plant remains can be found, both outside and within aggregates, as becomes clear from the increased proportions of POM in aggregate density fractions. In profile C the separation of mineral and organic layers has become even more explicit. The Ah horizon is no longer biologically active, roots have retreated into the thick litter layer (where nutrients become available through decomposition on the spot), leading to a reduced presence of free POM and of POM present in aggregates. The shift to fine intra-aggregate-POM in profile C is the result of ageing. We assume that the Ah in this profile is a slowly vanishing relict of the originally present vermimull.

The separation of organic and mineral soil parts, first within soil horizons, later between soil horizons, can be explained by decreasing earthworm activity. In profile A, soil, including earthworm casts, is reworked repeatedly by earthworm activity, leading to organic matter present in humic shape, and a relatively low presence of open worm channels. In profile B, earthworms still incorporate plant litter into casts, but reworking of the material does not often take place. Whether this is due to too low nutritive value of the remaining POM in the casts or to other environmental conditions related to acidification of the soil cannot be concluded from our observations. In profile C newly formed plant litter is no longer incorporated into the mineral layer, and the relative contribution to decomposition of mesofauna has increased. This leads to decomposition on the spot, with subsequent release of nutrients on the same location, and increased root abundance in the Mh-horizon, thus outside the mineral soil, occurs. The remaining Ah-horizon slowly ages. However, remains of organic material occluded in aggregates can prevail for a long time.

The trend in segregation between mineral and organic material related to decreasing earthworm activity is the opposite process as that described by Stockdill (1966) and Hoogerkamp et al. (1983). They initially found an external mat of decomposing organic matter and living roots, and, with increasing earthworm activity, a mixing in of organic matter into the mineral layers. They did not look at the aggregate level, but unpublished observations of Marinissen on micromorphological sections of the Dutch polder soil indicate the same processes on the aggregate level in the aggrading process. Thus the aggregate level is an important observation level for organic matter studies in soils with earthworm activity.

The trend in vegetation indicates that going from profile A to C less nutrients become available. The decrease in earthworm activity thus seems to be related with an overall decrease of SOM and nutrient dynamics.

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